Long-Range Propagation through Internal Waves

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LONG-TERM GOALS

This project aims to understand the fluctuations in low frequency (100 Hz, for example) acoustical propagation in the ocean over long distances (50 km to thousands of km), as well as other effects of internal waves and other small-scale variability in the speed of sound.

OBJECTIVES

The objective is to model results of recent low-frequency, deep-water acoustic-propagation experiments, constraining the model environment from the measurements of those environments. Phenomena such as intensity fluctuations and deep arrivals are of more concern than travel time fluctuations, as the physics of travel time fluctuations is much better understood.

APPROACH

Simulation of acoustic propagation in a model ocean with internal waves is used to study the effects of internal waves on the propagation. A highly accurate mode code has been developed for these studies.

WORK COMPLETED

The mode code has been developed and verified. Studies of the propagation starting with a single mode whose turning depth is within the main thermocline have begun. A comparison with transport theory has been made, and a new phenomenon in the propagation has been discovered.

RESULTS

Coupled modes are the basis for a full-wave propagation calculation through sound speed variability, yet they provide more insight than parabolic equation calculations. A new highly accurate coupled mode code has begun to be applied to long-range, low-frequency propagation. A very peculiar feature relating adjacent modes is found when a single moderately high mode is sent. This feature would rule out the validity of transport theory under the textbook condition for the transport approximation, but this condition is far too pessimistic; the validity of transport theory must be addressed separately.

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Initial conditions were chosen to be mode 50 at 100 Hz. Propagation for 1200 km was calculated. Loss processes were assumed absent, so conservation of intensity could be used to test the accuracy of the numerical propagation scheme. The sum over modes of the modal intensities, which is the same as the vertically integrated horizontal intensity, was found to be constant to 1.3 parts per billion over the 1200 km range. Many other codes do not pass this test.

Results of propagation through one particular realization of a Garrett-Munk internal wave field are shown in figure 1. The deep arrivals correspond to the higher modes that get produced by internal waves. For example, suppose mode 70 is created from mode 50 at 600 km. This would arrive at 1200 km at the same time as an unscattered mode 60, and would extend deeper because mode 70 has a deeper lower turning depth than mode 60.

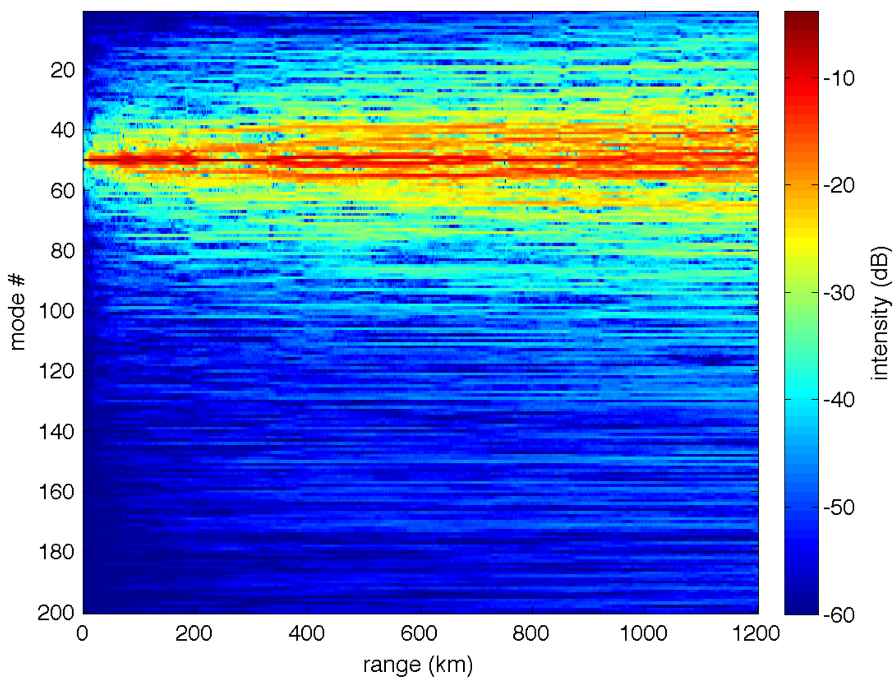

Figure 1. Mode intensities for the 200 retained modes at 100 Hz. The initial condition is pure mode 50. The modal content spreads out with range. At 1200 km, most of the intensity is in a 20 mode band surrounding the initial mode.

A magnification of this figure is shown in figure 2. This shows a very strange phenomenon. Several times, the starting mode becomes very small in intensity, only to regain its dominance later. The most notable of these events in this particular realization of the internal wave field is a 200 km stretch between 400 and 600 km. At two ranges in this interval, mode 50 is 30 dB down, only to later return to nearly half the intensity it started with.

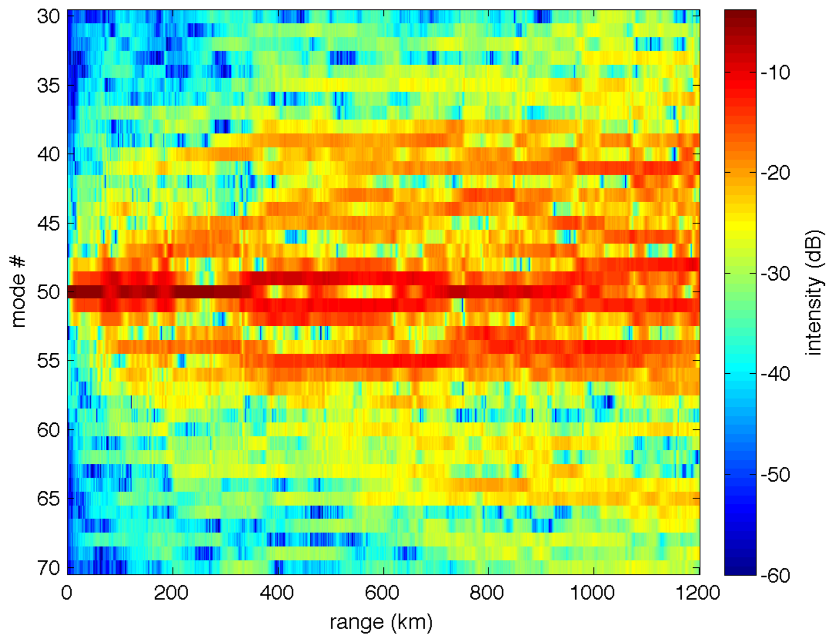

Figure 2 A magnification of figure 1, showing modes 30 to 70. One sees that mode 50 becomes very weak, most notably between 400 and 600 km, but later, around 750 km, again dominates the intensity.

Figure 3 shows mode 50 compared to the sum of the four neighboring modes, and to the sum of all five of these modes. One sees that when mode 50 decreases suddenly, the four neighboring modes increase by about the same amount, and vice-versa. The sum of all five modes behaves qualitatively as one would expect each mode to behave.

Because the behavior of the starting mode is so strange, it was verified that solving the PE with the same initial condition, and projecting onto modes showed the same phenomenon. This phenomenon is not understood, but it may be connected with the scattering being almost completely near the upper turning point of the mode, and with the existence of sharp arrivals in the time-depth plot, know for its shape as the accordion.

The sharp transitions of mode 50 shown in figure 3 are inconsistent with the textbook condition of validity for transport theory, which requires transitions to be much smaller than an e-folding. However, work I did a few years ago shows that the textbook condition applies to a form of transport theory not used in practice, and is far too pessimistic for the commonly used form. However, these results suggest that a verification of transport theory is in order. (John Colosi verified the application to lower modes.)

A comparison to John Colosi's transport code was made fon the mode intensities. His result was consistent with an average of a number of independent runs of the mode code. Thus, for one important set of statistical quantities, transport theory is valid. Further tests will be made. In particular, it would be interesting to describe the strange behavior by a statistical moment, and see if transport theory correctly predicts that moment.

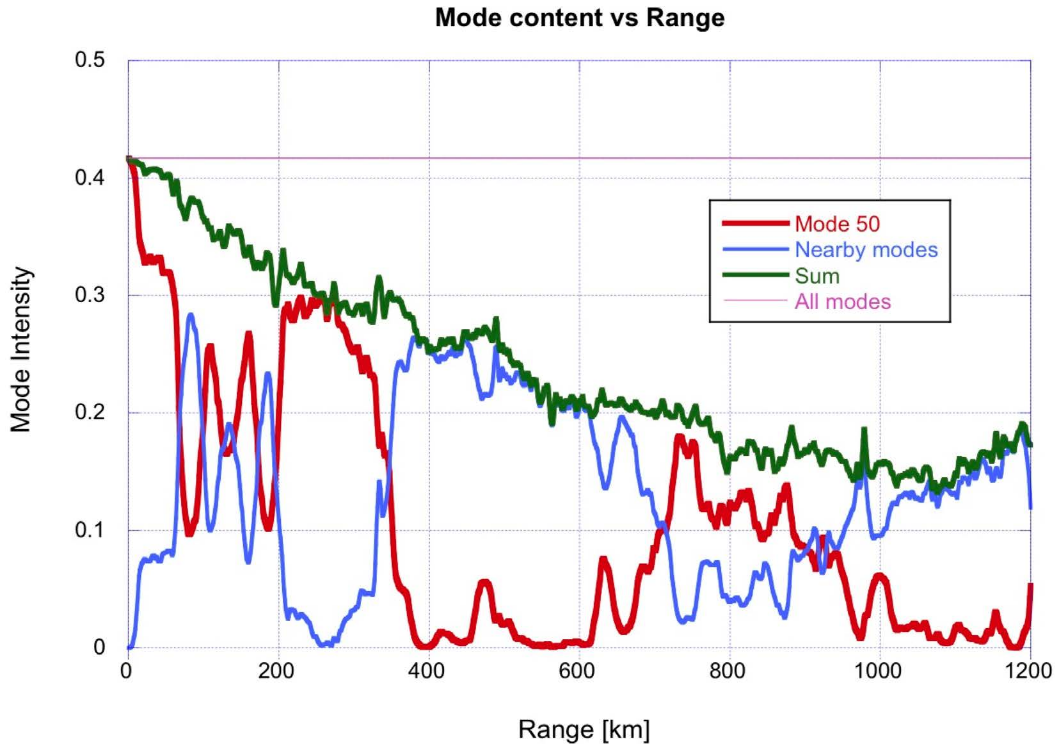

Figure 3 The strange behavior of mode 50 (the starting mode) is mirrored by the four neighboring modes (nearly equally split between the smaller two modes and the larger two, not shown). The sum of all five qualitatively resembles the expectation from the concepts that go into transport theory, whereas the individual modes strongly disagree with that expectation.

IMPACT/APPLICATIONS

Most studies of fluctuation effects have been applied to travel time fluctuations. Travel time is dominated by large-scale environmental variability, and is relatively well understood. The studies in this project are mostly in regard to small-scale variability, which are dominant in intensity fluctuations and spatial coherence, as well as to the "deep arrivals", which are significantly deeper than the rays in a range-independent sound speed field. For the small scales, the fact that propagation is mostly horizontal, along the stratification, is essential, and well-tested theories for vertical propagation (in the atmosphere) cannot automatically be carried over.

RELATED PROJECTS

The main Applied Physics Lab low-frequency, long-range propagation project (Jim Mercer, PI) is closely coordinated with this project. In fact, the two projects will be combined into one in 2012.